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In-House Test Program
Report No. 5

Hot Soak Temperature Constraints

February, 1976

Thomas Rarick

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The goal of the in-house evaporative emission enclosure (SHED) testing is to develop a concise, accurate, and practical evaporative emission test procedure. One of the critical questions requiring evaluation is whether or not the enclosure method of testing for hot soak emissions presents abnormally high vehicle temperatures. In order to evaluate whether these temperatures do occur in the enclosure, hot soak tests were conducted in the enclosure and in the shop soak area and various temperatures were monitored. The objective of this study was to determine if a maximum enclosure ambient temperature should be specified for the hot soak test and to determine what a reasonable maximum temperature would be with respect to other phases of the test procedure. Also, temperatures near and on the surfaces of the inner and outer walls of the enclosure were measured.

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Appendix B - Test Data for Enclosure Temperature Profiles

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1. Introduction

The goal of the in-house evaporative emission enclosure (SHED) testing is to develop a concise, accurate, and practical evaporative emission test procedure. One of the critical questions requiring evaluation is whether or not the enclosure method of testing for hot soak emissions presents abnormally high vehicle temperatures. The enclosure may be a barrier to heat dissipation during the hot soak portion of the evaporative emission test and result in higher SHED interior temperatures which could result in increased vehicle temperatures. Increased vehicle temperatures, especially in the carburetor bowl and fuel tank, would tend to cause an abnormally high generation of fuel vapors.

In order to evaluate whether abnormally high temperatures do occur in the enclosure, hot soak tests were conducted in the enclosure and in the shop soak area and various temperatures were monitored. The objective of this study was to determine if a maximum enclosure ambient temperature should be specified for the hot soak test and to determine what a reasonable maximum temperature would be with respect to other phases of the test procedure. Also, temperatures near and on the surfaces of the inner and outer walls of the enclosure were measured. The purpose of gathering such data was to evaluate how enclosure temperatures could be reduced.

9. Summary and Conclusions

The purpose of this study was to determine whether or not the use of a vehicle enclosure (SHED) for measuring hot soak evaporative emissions would cause abnormally high ambient and vehicle temperatures. It was reasoned that the carburetor bowl temperatures would be the most critical. Testing consisted of soaking the five test vehicles both in the enclosure and in the shop soak area for two hours immediately following a dynamometer drive. Ambient temperatures in the enclosure on the average rose 10°F more than in the soak area with a range of from 5 to 14°F. Peak carburetor bowl temperatures were 12°F higher on the average in the enclosure. The SHED also limited the cooling of the fuel tank. For certain vehicles internal tank temperatures rose approximately 2°F more in the enclosure than in the soak area. Increases in the fuel temperature are expected to have a much smaller effect on emissions than the increased carburetor bowl temperatures. The fact that the enclosure does present a more severe temperature condition points to the need to limit the maximum ambient temperature in the enclosure by setting a maximum temperature limit.

The ambient temperature range specified for other portions of the exhaust and evaporative emissions test is 68-86°F (20-30°C). It would seem appropriate to recommend that the same temperature range be specified for the hot soak portion of the test. However, some problem may exist in maintaining the maximum temperature below 86°F for some vehicles. Therefore, if a slightly higher maximum temperature could be met for the "hottest" vehicle tested using simple techniques for heat transfer, whereas an 86°F maximum temperature could only be met by elaborate techniques such as a closed loop air conditioning system, then it would seem reasonable to recommend up to a 90°F maximum allowable SHED ambient temperature as in the SAE(J171a)(1) test procedure. Techniques to cool the SHED include increasing the inner and outer surface area of the enclosure, maximizing the temperature gradient across the wall surfaces and increasing air circulation.

A limited amount of testing was done to determine the effectiveness of increased air circulation inside and outside the SHED. The results of this testing showed that lower SHED ambient temperatures were achieved, but carburetor bowl and tank temperatures were the same or higher. Achieving an 86°F maximum temperature would require approximately 5°F more cooling than was achieved with the additional fans, however. It is believed that this additional cooling can be achieved by lowering the soak area ambient temperature, and affixing cooling fins to the SHED. If testing shows that these steps do not result in maximum temperatures below 86°F for the hottest vehicles, it is recommended that a slightly higher maximum temperature requirement be adopted rather than the use of a more elaborate cooling system.

3. Technical Discussion

The concern over the possibility of encountering abnormally high ambient temperatures in the enclosure is due to the possibility that this condition will cause abnormally high carburetor bowl and fuel tank temperatures. If these temperatures increase, a greater amount of fuel vapors could be generated from the bowl and tank and this would create an abnormal load on the evaporative control system. Whether or not this would actually result in higher emission levels from the vehicle would depend on the design of the evaporative control system and on whether or not a large amount of fuel vapors was already stored. Abnormally high temperatures should be avoided to reduce test variability and to provide an equitable test for different vehicles, regardless of whether or not increased fuel vapor generation would show up as a measureable increase in emissions.

The effect of temperature on fuel vapor generation can be expressed by a distillation curve of the test fuel used. Figure 3-1 shows such a curve relating the temperature of the fuel with the volume percent distilled. The figure shows two curves; one for fuel vapor temperatures and one for liquid fuel temperatures. It can be seen from the figure that the fuel in the fuel tank would not begin distilling until the liquid temperatures are elevated to 135°F. This temperature level would not be expected during a normal hot soak, and as normal certification test fuel has a similar initial boiling point, fuel vapors would not be generated from the fuel tank as a result of fuel distillation. However, some increase in the vapor from the fuel tank could be expected during the hot soak test if temperatures are increasing: (1) in the vapor space - causing the vapors to expand and be forced through the evaporative emission storage media, and (2) in the liquid fuel - causing a higher concentration of hydrocarbons in the vapor space.

Peak temperatures in the carburetor bowl during a hot soak will depend on, among other things, the size of the engine and will range from 150-180°F. Initial bowl temperatures at the start of the hot soak test are normally between 110 and 120°F. It can be seen from Figure 3-1 that an increase in fuel vapor generation could be expected due to increased peak carburetor bowl temperatures. The percent increase due to a 10°F increase in carburetor bowl temperatures from 160°F to 170°F can be estimated using the following equation and values from Figure 3-1.

$$\text{Increased \% of Evaporated Fuel} = \frac{\text{\% Evaporated at 170°F} - \text{\% Evaporated at 160°F}}{\text{\% Evaporated at 160°F}}$$

Substituting the values from figure 3-1 into this equation shows a 33% increase in the volume percent evaporated due to a 10°F increase in fuel bowl temperatures from 160°F to 170°F. The actual percent increase will be dependent on the actual peak bowl temperatures, but this example does serve to illustrate that a 10°F increase can have a significant effect.

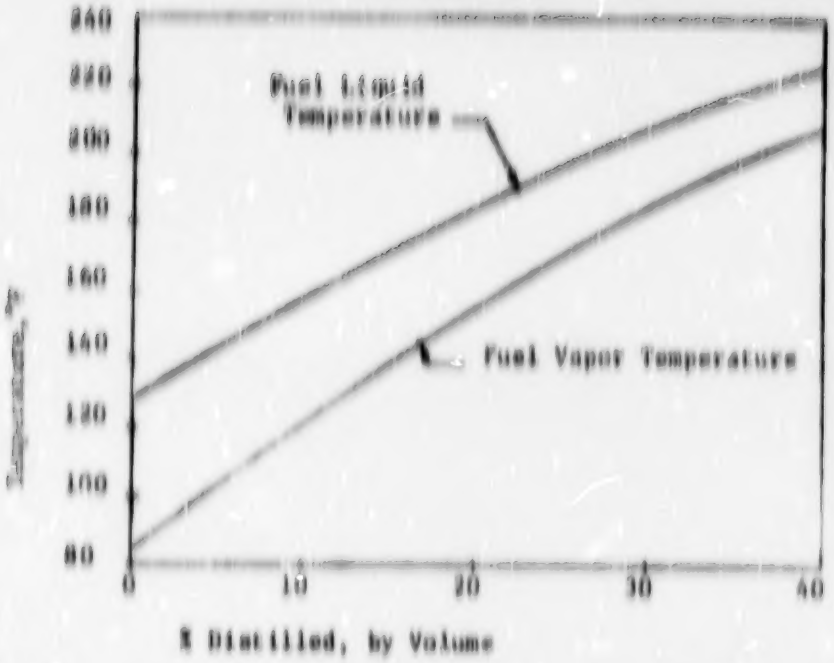

Figure 3-1 Distillation Curve For Test Fuel.

From the above discussion it appears that if increased carburetor bowl temperatures are seen in the enclosure as opposed to temperatures experienced during a hot soak in a large soak area, then some means of controlling the temperature in the enclosure may be required. How this can best be accomplished can be determined by examining what mechanisms limit the transfer of heat away from the vehicle. The vehicle during a hot soak must dissipate large amounts of heat energy to the surrounding air and then this warmer air must be moved away from the vehicle and replaced by cooler air. In the soak area, air warmed by the vehicle will rise and be replaced by cooler air. The SHED air is a fixed parcel of air and is therefore not allowed to rise and heat transfer must occur primarily across the ceiling and wall surfaces by conductive heat transfer.

Improving the conductive heat transfer across the walls of the SHED will improve the heat dissipation away from the vehicle during a hot soak. The following equation can be used to quantify steady-state conductive heat transfer through a flat surface such as the walls of the SHED:

$$q = \frac{A(\Delta T)}{f_i + R_{wm} + f_o}$$

where: q = Rate of heat transfer

A = Surface area of the wall

ΔT = Difference in the inside and outside temperatures

f_i and f_o = Inner and outer wall surface heat transfer coefficients

R_{wm} = Resistance to heat transfer due to the wall itself.

This equation cannot be used to quantify the heat transfer capabilities of a particular SHED design during a hot soak, because the test does not represent a steady-state condition, and the geometry of SHED is much more complex than a plane surface. It can be used, however, to qualitatively determine what steps can be taken to maximize the rate of heat transfer (Q). First, the surface area (A) of the enclosure can be increased by adding cooling fins to the inner and outer wall surfaces of the enclosure. Secondly, the temperature difference (ΔT) can be increased by cooling the outer walls of the enclosure by lowering the outside ambient temperature, by blowing cooler air against the walls, or by water cooling the walls. The inner and outer wall surface coefficients (f_i and f_o) are indicative of the difficulty of transferring heat from the air to the solid wall material. These coefficients are dependent on the velocity of air moving against the wall surface. The coefficients become smaller as the velocity increases and, thus, using fans to circulate air against the enclosure walls will increase heat transfer. Lastly, the resistance of the wall material itself can be lowered by (1) selecting a material with a high thermal conductivity, and (2) making the wall as thin as is practicable.

A semiquantitative use of the above equation and a consideration of practical limitations can give an indication of the most favorable ways of increasing the heat transfer. The addition of cooling fins has the advantage of requiring little maintenance, and it has a high capacity for increasing heat transfer. If you can double the inner and outer surface area of the SHED walls, you should be able to roughly double the heat transfer. The steady-state approximation is somewhat misleading, however, because as soon as you increase the heat transfer, the ΔT across the wall decreases which in turn decreases the heat transfer. The use of cooling fins would also increase the expense of the SHED.

Cooling the outer surface of the SHED wall to increase the temperature gradient (ΔT) across the wall could require either some source of cooler air or cooler water. This necessitates a sizeable hardware

expenditure, as well as a maintenance and operating expenditure. Thus, the major drawback of this technique would be its cost and complexity. The effectiveness of this technique is considerable, however. The ambient temperature in the enclosure could be reduced significantly. It would be limited though because hydrocarbons could condense on the walls of the enclosure if the wall temperatures were reduced too much. This same problem would exist with a closed loop airconditioning system.

The denominator of the equation is the sum of three terms (f_i, R_m, and f_o). The effectiveness of reducing any one term must be evaluated with respect to the resulting reduction in the size of the entire denominator. The inner and outer wall surface heat transfer coefficients (f_i and f_o) are much larger than the wall material resistance term in the equation. (The sum of the wall surface coefficients ranges from 0.4 to 1.4 hr-ft^2-°F/BTU) depending on the amount of air circulation, whereas the wall material resistance ranges from .1 to .0002 hr-ft^2-°F/(BTU) depending on the material used and its thickness). Thus, if the air is still inside and outside the enclosure, increasing the air circulation will be more effective than changing the wall material. The most practical way of reducing the denominator of the equation cost effectively would be to use a material that is a good heat conductor and is inexpensive, and to use enough air circulation to achieve the desired goals. Presently there is some air circulation required inside the SHED and it is likely that there is some around the enclosure. How much more is required would have to be determined experimentally. The greater the amount of air circulation required, the greater the hardware, and maintenance cost, however.

From the above discussion a balanced system to reduce temperatures at a reasonable cost is suggested as follows: (1) Cooling fins added to the inner and outer wall surfaces, (2) Blowers positioned so as to direct air against the cooling fins, (3) Walls made of thin sheets of aluminum, and (4) Reduced ambient soak area temperatures to maximize the temperature difference across the SHED walls. Such a system would have low operating costs, relatively inexpensive initial capital cost compared with a water cooler SHED or a closed loop air-conditioning system, and would require little maintenance. Whether or not this system would meet an enclosure maximum ambient temperature of 86°F would have to be determined experimentally. Although this is not in the scope of this report, such data need to be gathered in the near future.

1.1 Program Objective

The purpose of this study is to determine whether or not a maximum SHED temperature should be specified for the hot soak portion of the evaporative emission test and to determine what a reasonable maximum temperature would be.

1.0 Program Design

In order to determine if the SHED presents an abnormal condition with respect to encountered temperatures, the ambient, internal and external tank and carburetor bowl temperatures were measured for a vehicle undergoing a 2 hour hot soak, both in the SHED enclosure and in the shop area. It is assumed that the vehicle soaking in the shop soak area would be representative of a real life situation from the standpoint that the vehicle is allowed to cool-off by means of natural convective heat transfer. Thus, a comparison of shop and SHED enclosure temperatures during a hot soak is expected to show whether or not the SHED presents a more severe ambient condition.

Five vehicles which varied in overall size, engine size, and other vehicle parameters were used during the comparative testing. A minimum of 5 tests on each vehicle were conducted for both shop and SHED soaks. Temperatures were recorded every ten minutes for two hours even though the hot soak evaporative emission test is only ran for one hour, in order to gain a better understanding of the temperature changes. This allowed for the establishment of typical two hour temperature profiles for both a shop and SHED soak.

The temperatures were taken in conjunction with other testing. Evaporative loss data were recorded for the SHED enclosure hot soak tests but similar data could not be obtained for shop hot soak tests.

A second part of the test program was aimed at evaluating the temperatures across the SHED wall in order to evaluate what heat transfer methods could be employed to promote more rapid heat dissipation from the SHED. Temperatures were taken at the wall surface, 1/2", 1", 2", 4", 6", 8" and 10" from both inside and outside the enclosure wall surfaces. These data were taken during hot soak tests with a Ford Galaxie 500.

A third part of the testing was aimed at determining whether or not increased air circulation at the SHED outer wall and inner wall surfaces aided in lowering temperatures. Again, various vehicle temperatures and the ambient SHED temperature were recorded. Only the New Yorker was used for these tests.

Hot soak tests conducted in the SHED immediately followed a 1975 FTP exhaust emission test dynamometer cycle. Hot soaks conducted in the shop soak area followed either an Urban Dynamometer Driving Schedule (usually called an LA-4) or a one-hour AMA road route followed by a LA-4 dynamometer cycle. The reason for the differences in the driving cycles was not related to this evaluation but concerned the ability to gather the needed data during other evaporative emission data gathering tasks.

The time from the end of the vehicle drive to the start of the hot soak differed slightly for the tests conducted in the SHED or shop. Data gathering for tests in the shop area started immediately after the engine was shutdown. Tests conducted in the SHED were delayed by 1 or 2 minutes due to the need to move the vehicle into the SHED and shut the enclosure doors after engine shutdown. Even though there was a slight delay in starting the soak in the SHED, this should not affect the comparison of maximum temperatures measured for either a shop or SHED soak.

3.3 Test Facilities and Equipment

The Light Duty Vehicle Evaporative Enclosure used during testing is shown in figure 3-2. The soak area surrounding the enclosure was used to park the vehicle during shop soaks. This area along with the recorder for recording temperatures mounted on top of the vehicle is shown in figure 3-3. The shop area ambient temperature is normally kept at 76-86°F. For tests in the shop area, actual ambient temperatures averaged 75.9°F. For tests conducted in the SHED, the actual soak area ambient temperatures averaged 77.6°F.

Esterline Angus temperature recorders utilizing iron-constantan thermocouples were used to measure and record temperatures. Some of the thermocouples used were grid type thermocouples, and these were used specifically to measure tank skin temperatures, and the inner and outer surface temperatures of the SHED enclosure wall.

3.3.1 Evaporative Enclosure (SHED)

The SHED enclosure used during testing was made by Olson Laboratories. The enclosure used is nominally 8 ft. high by 10 ft. wide by 20 ft. long and has a measured volume of 1340 ft^3. The lower portion of the walls and doors and the entire rear wall of the enclosure are made from panels with a masonite core covered with thin sheets of porcelain enamel coated aluminum. The upper portion of the walls and doors are made of wire reinforced plate glass. The ceiling is made of a sheet of 5 thousandths of an inch thick Mylar plastic. The floor is made of a sheet of anodized aluminum covering marine grade plywood. The above materials accounted for roughly 700 ft^2 of surface area each. The supporting frame of the enclosure was made of anodized aluminum and the surface area of the frame was roughly 50 ft^2. The overall surface area of the SHED is roughly 8050 ft^2.

3.3.2 Test Vehicles

Five (5) 1975 MY vehicles were used in this evaluation. The criteria for vehicle selection was that they had been in use for over 90 days and had accumulated 4000 miles. Additional criteria were engine-fuel tank configuration and exhaust control system. Specifics of each vehicle are shown in Table 3-1. In addition, a 1975 Ford Galaxie 500

Figure 3-1. Evaporative Enclosure

Figure 3-2. Vehicle Soaking in the Shop Area with Temperature Recorder Mounted on the Top.

Table 3-1. Test Vehicle Descriptions

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

was used for wall temperature profile data gathering during hot soaks in the enclosure.

3.3.3 Test Fuel

Indolene Type HO lead-free test fuel was used throughout the program. Additional information regarding the distillation properties of the test fuel was discussed earlier in this section (see Figure 3-1).

3.4 Test Procedures

3.4.1 SHED vs. Shop Hot Soaks

Each of the five (5) vehicles underwent the two test sequences for a SHED and shop hot soak as shown in Figure 3-4. The additional testing prior to the SHED hot soak was done in conjunction with separate evaporative emission related testing. Temperature data were recorded every 15 seconds. Hydrocarbon concentration as measured by a Flame Ionization Detector (FID) for tests conducted in the SHED enclosure were recorded continuously. Hydrocarbon concentration measurements for soaks in the shop area were not possible.

3.4.2 Enclosure Temperatures

A 1975 Ford Galaxie 500 was used to evaluate the temperature profile across the SHED wall during a one hour hot soak. The vehicle was driven over an LA-4 exhaust emission test cycle and then parked in the enclosure for one hour. Temperatures at the wall surfaces, 1/2", 1", 2", 4", 6", 8", and 10" from the wall surfaces were measured and recorded at 20 min. intervals during the one hour soak. The temperatures were taken approximately 6 feet above the floor and approximately in line with the engine compartment of the vehicle along one of the side walls of the enclosure. Three replicate tests were conducted.

3.4.3 Hot Soak Tests with Additional Fans

Additional fans placed outside and inside the enclosure were used to increase the movement of air to the wall surfaces. Tests were conducted using the New Yorker only and consisted of a one hour hot soak following an FTP exhaust emission cycle. The placement of the fans is shown in figure 3-5. The external fans were mounted approximately 15" above the floor and were similar to the fans used to cool the vehicle during the exhaust emission test. The fans used inside the SHED were squirrel cage blowers set in the back seat of the vehicle. Air was directed against the wall through a 7" diameter flexible duct leading from the blowers.

For this portion of testing, vehicle temperature data as well as SHED ambient temperature data were collected. Also enclosure hydrocarbon concentration as measured by a Flame Ionization Detector (FID) was recorded continuously.

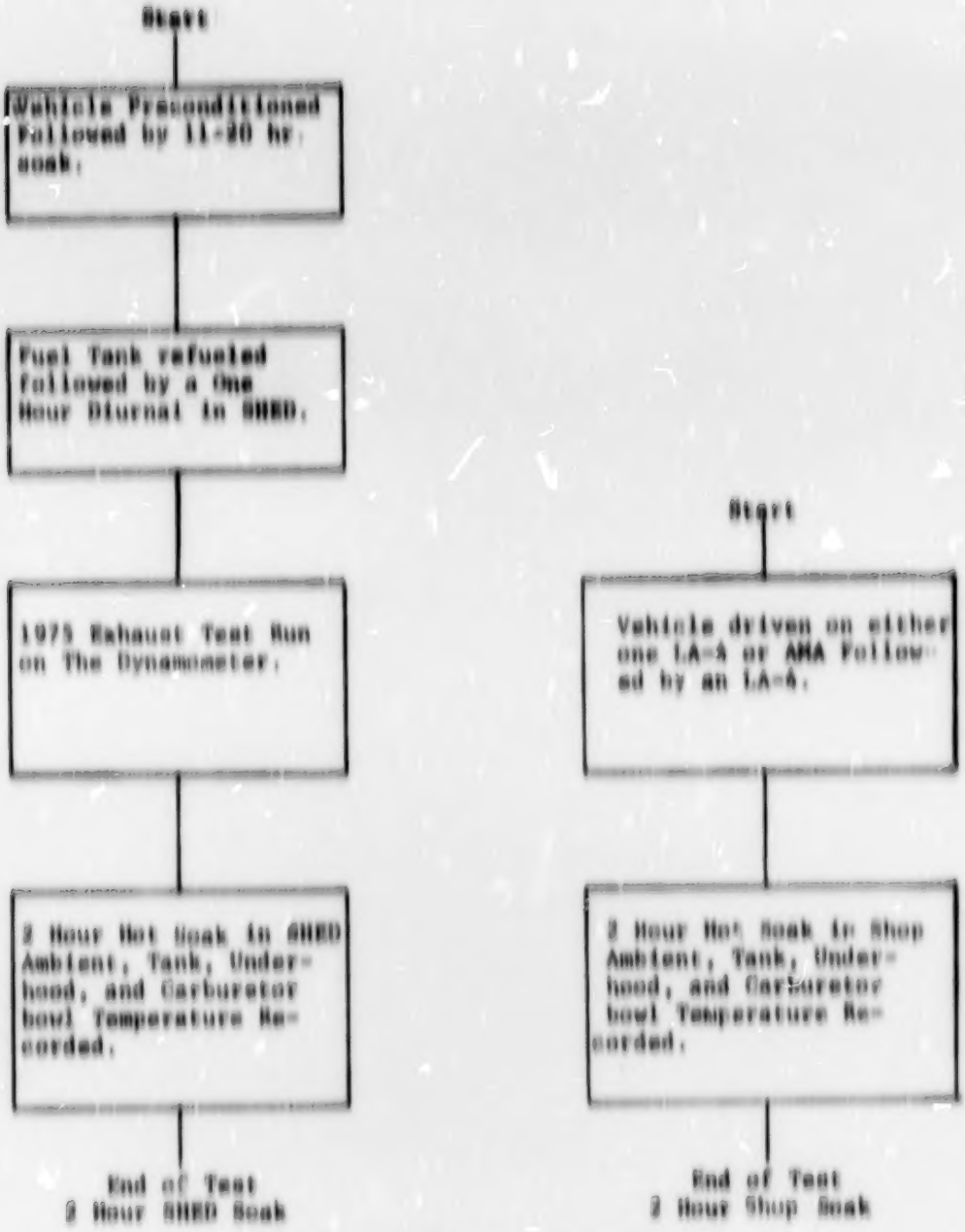

Start
Vehicle Preconditioned Followed by 11-20 hr. soak.
Fuel Tank refueled followed by a One Hour Diurnal in SHED.
1975 Exhaust Test Run on The Dynamometer.
2 Hour Hot Soak in SHED Ambient, Tank, Underhood, and Carburetor bowl Temperature Recorded.
End of Test 2 Hour SHED Soak
Start
Vehicle driven on either one LA-4 or AMA Followed by an LA-4.
2 Hour Hot Soak in Shop Ambient, Tank, Underhood, and Carburetor bowl Temperature Recorded.
End of Test 2 Hour Shop Soak

Figure 3-4 Sequence of Events

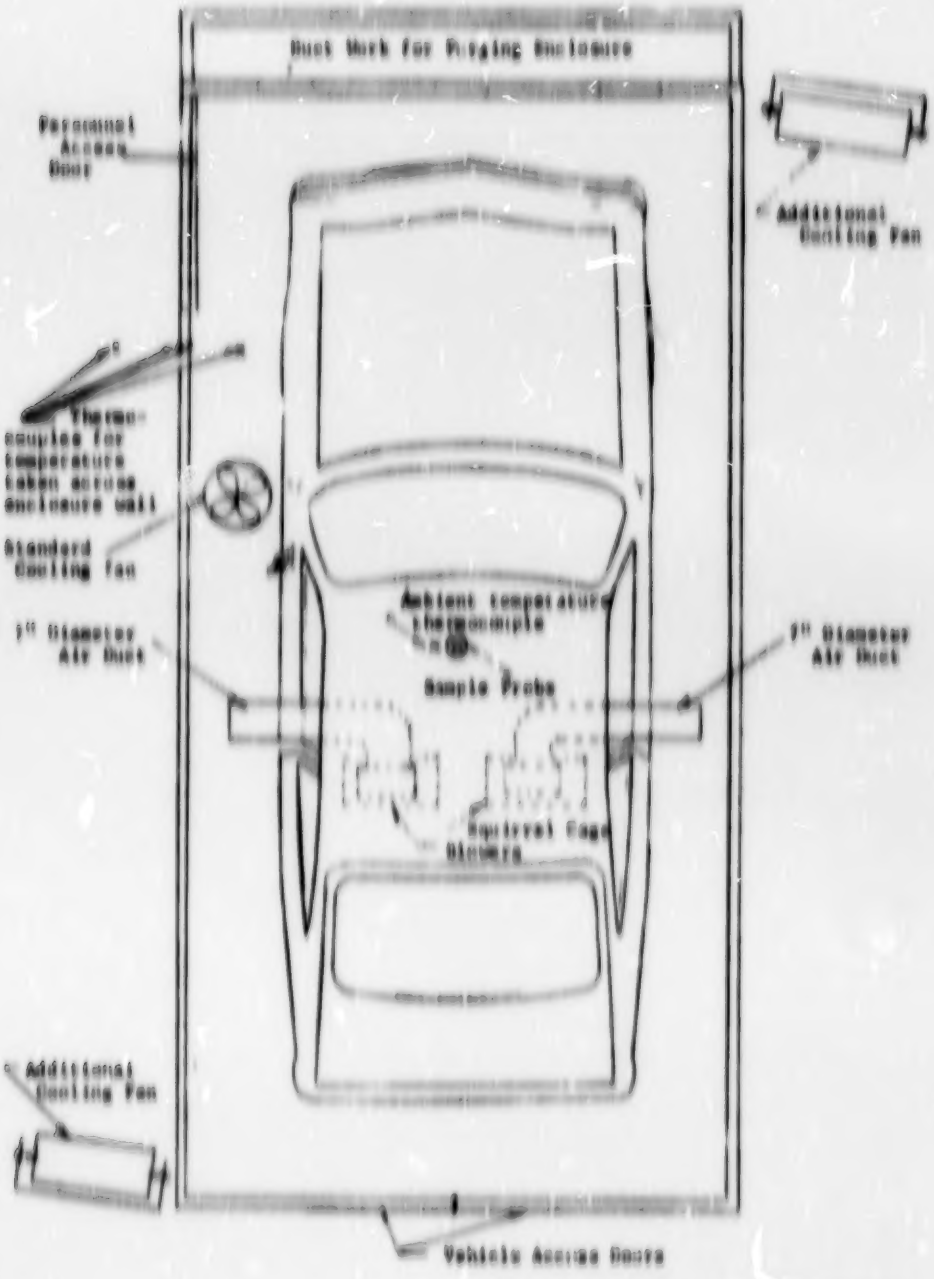


Figure 3-5 Equipment Placement for Tests conducted with Additional Cooling Fans.

4. Test Results

4.1 SHED vs. Shop Hot Soaks

A total of 57 2-hour hot soak tests were conducted with 33 of these tests being conducted in the SHED enclosure and 24 conducted in the shop soak area. The individual temperature data for these tests are presented in Appendix A along with the average temperature data.

Temperature data for each of the five vehicles individually and the composite of all five vehicles are shown graphically in Figures 4-1 through 4-4. For the composite graphs the data were reduced by averaging the average values for each of the five vehicles. This method of data reduction should have eliminated bias due to unequal numbers of test results between vehicles. The composite graphs for external tank and carburetor bowl temperature were constructed from data from four vehicles only. External tank data were not recorded for the Volkswagon and carburetor bowl data could not be obtained for the Volkswagon as it had fuel injection

Figure 4-1 shows that ambient temperatures were higher in the SHED than in the soak area. For all the vehicles it appears that the initial temperatures in the SHED were on the average 5°F higher. In reality, the average initial temperatures in the SHED were only 1.7°F above the average temperatures in the soak area. The 1.7°F higher temperatures occurred due to the daily soak area temperature fluctuations. The difference between the actual 1.7°F and the apparent 5°F higher SHED temperatures was due to the fact that the vehicle sat in the enclosure for between 30 and 60 seconds while thermocouples were being connected and the doors were being closed prior to the start of the test. Thus, the curves for tests in the SHED start somewhat after time zero. Projecting the curves for the SHED ambient temperatures back roughly a minute to time zero shows that the initial temperatures were roughly the same for all of the vehicles. The time delay between the start of the key-off operation and the start of the SHED hot soak tests also affected other temperatures measured. Peak ambient temperatures in the SHED were on the average 10°F higher than in the soak area. The worst case was for the New Yorker for which maximum temperatures were almost 95°F and this maximum temperature was roughly 14°F higher than the maximum temperature recorded for tests in the soak area. These differences take into account the difference in the ambient soak area temperatures (1.7°F higher for tests in the SHED than for tests in the soak area).

The internal and external tank temperatures are plotted in figures 4-2 and 4-3 respectively. The initial temperatures at the beginning of the hot soak period could have been affected by the handling of the vehicles prior to the hot soak and thus temperatures are plotted as the change in temperature from the start of the test. For tests in the soak

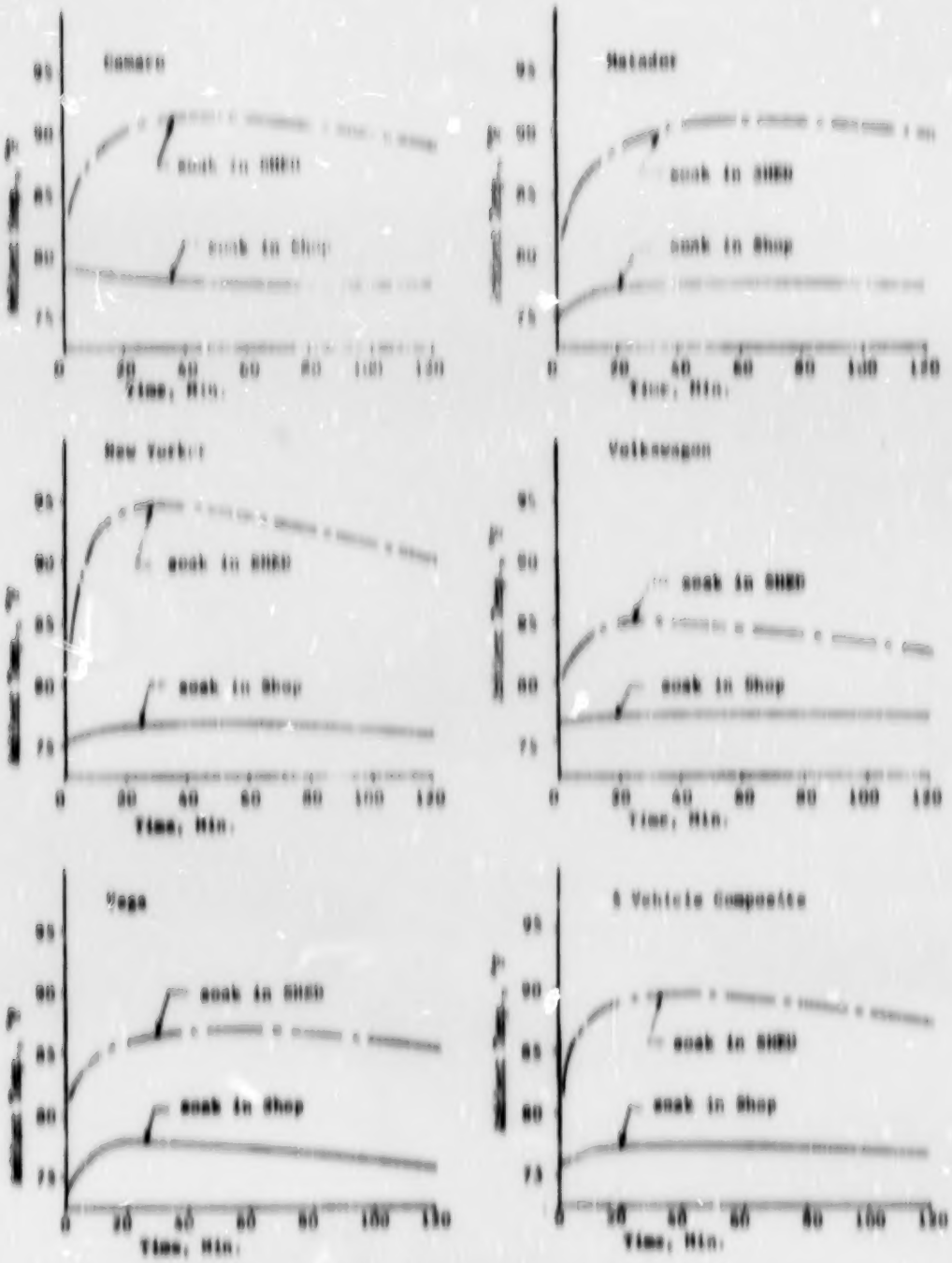


Figure 4-1 Ambient Temperature vs. Time for Hot Soak Tests in the SHED and in the Shop.

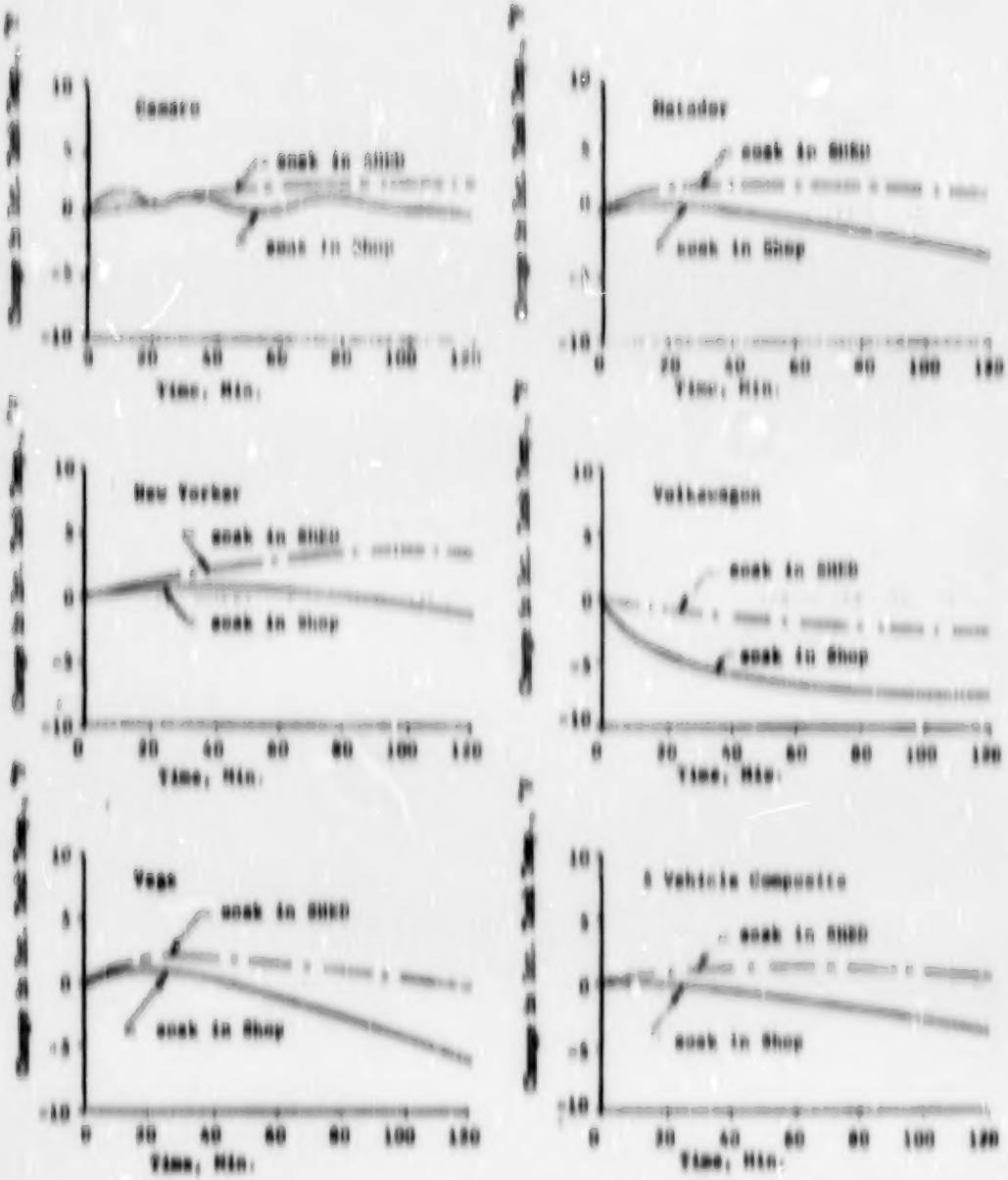


Figure 4-2 Change in Internal Tank Temperatures vs. Time for Hot Soak Tests in the SHED and in the Shop.

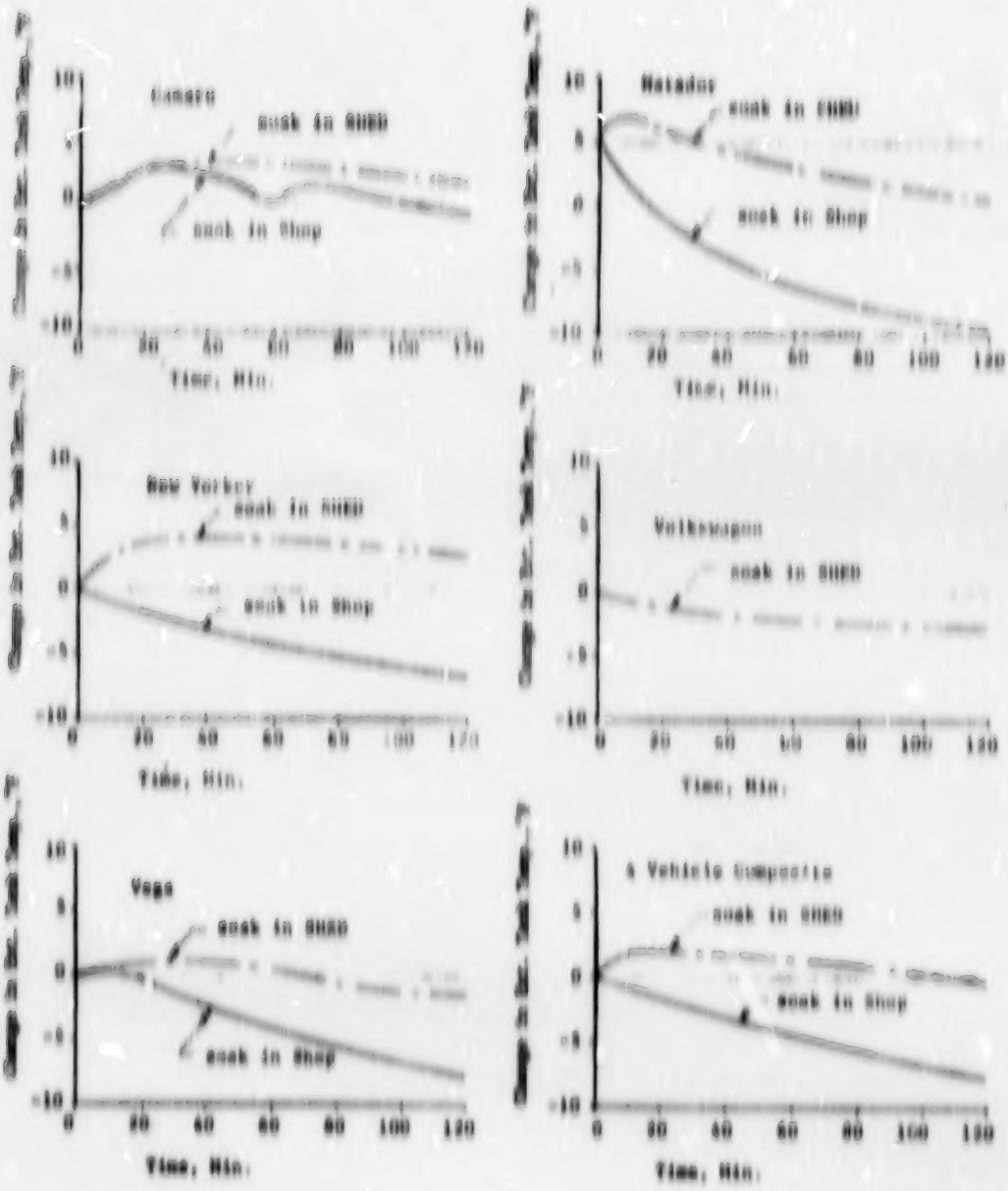


Figure 4-1 Change in External Tank Temperatures vs. Time for Hot Soak Tests in the SHED and in the Shop.

area, the fuel in the fuel tank was either at the ambient temperature of the soak area (approximately 76°F) or between 50 and 60°F if a fresh charge of fuel was needed prior to the preconditioning drive. For tests in the enclosure, the vehicle underwent a diurnal test prior to the start of the drive before the hot soak. The temperature of the fuel at the end of the diurnal would have been 84°F. Thus, the temperature of the fuel at the end of the drive could have been different for the two types of hot soak. The figures do show, however, that the cooling of the tank is inhibited due to the presence of the SHED. The composite graphs for internal and external tank temperatures show that the tank started to cool immediately in the soak area, but in the SHED the temperatures rose slightly before cooling. This general statement was not true for all vehicles tested, but a more severe condition did exist for all vehicles soaked in the SHED (with the possible exception of the Volkswagen for which external tank temperature data were unavailable). The effect of the tank temperatures on the generation of hydrocarbons is probably small, however. The maximum internal tank temperature measured was 96°F for the Matador. This temperature is roughly 30°F below the initial boiling point of the fuel used during the test program (see figure 3-1) and therefore there would be no increase in fuel generation due to distillation. The only increase in the fuel vapor loading on the evaporative control system from the fuel tank would be due to increasing vapor temperatures which would cause an expansion of gases in the vapor space which would force vapors through the control system. The peak tank temperatures would have a slight effect due to an increased concentration of vapors in the vapor space at higher temperatures. Vapor temperatures were not measured and therefore the actual expansion of gases in the vapor space could not be determined. The expansion would not be large, however, and the additional load on the evaporative control system would be small compared with the effect of increased emissions from the carburetor bowl.

Figure 4-4 shows the carburetor bowl temperatures during the two hour hot soak. The initial temperatures were roughly the same for hot soaks in the soak area or in the SHED. Peak temperatures, however, averaged 13°F higher in the SHED than in the soak area. The peak temperatures occurred at the end of the first hour of the two hour soak. The most severe case for carburetor bowl temperatures occurred for the Vega in which the peak carburetor bowl temperatures in the SHED averaged 164°F or 13°F higher than the 151°F average peak bowl temperatures in the soak area. Using this information and the information regarding fuel distillation in figure 3-1, the 13°F higher bowl temperatures will result in roughly 50% more fuel being distilled. Whether or not this increase in the evaporative control system loading would result in higher emissions measured during the test would depend on the control system type and its condition prior to the test. Regardless of whether or not it would cause higher emission results, the potential for this is present due to the increased generation of fuel vapors.

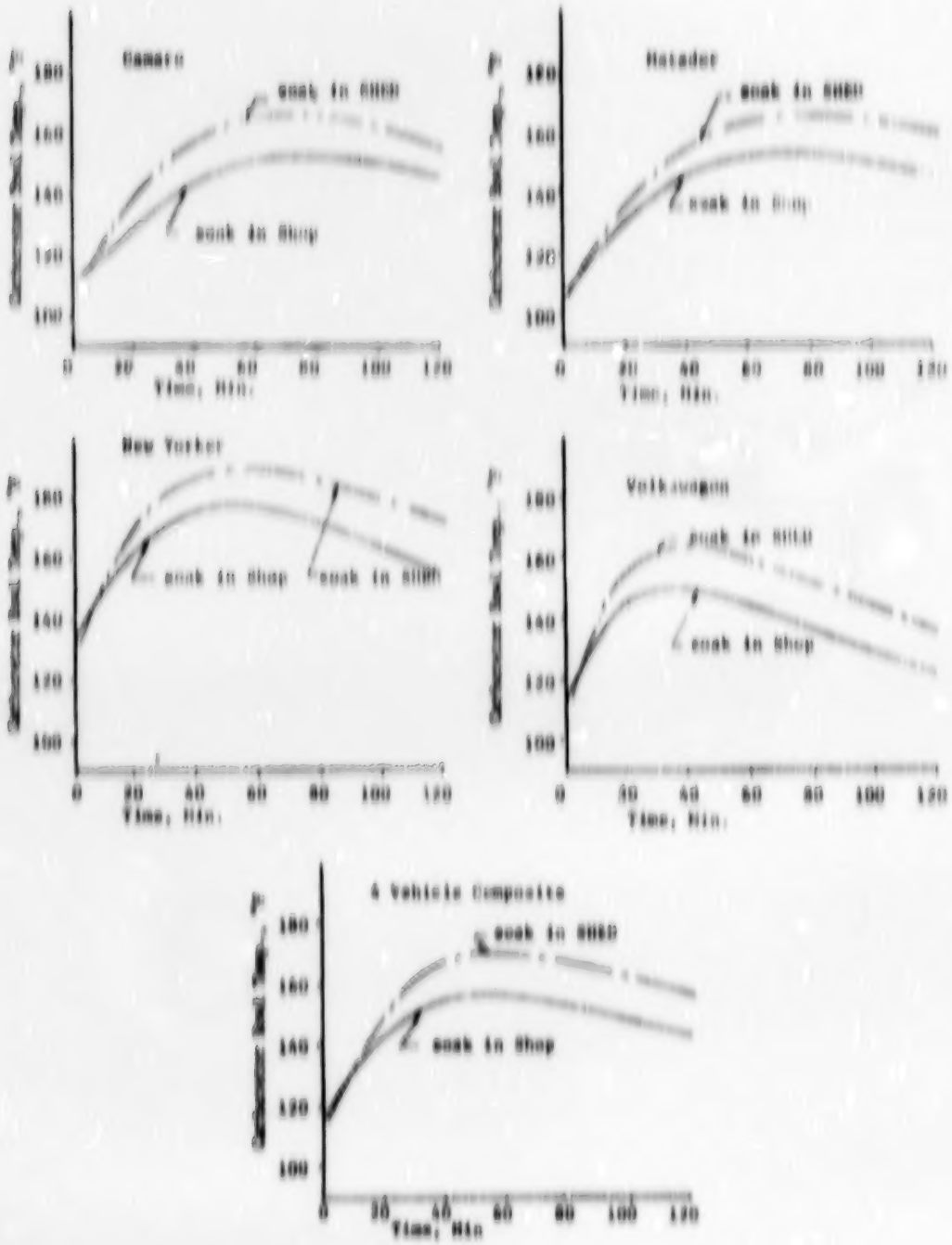


Figure 4-4 Carburetor Bowl Temperatures vs. Time for Hot Soak Tests in the SHED and in the Shop.

4.3 Enclosure Temperature Profile

Temperature data gathered during hot soak tests conducted in the SHED with a Datsun 500 are presented in Appendix B. Temperatures at 40 min. into the test were found to be at a maximum and thus only data for this time are presented. Figure 4-3 shows the temperature profile across the wall at that time. This figure shows that the temperature drop across the wall occurs in the 1/2 - 1 inch air layer on either side of the SHED wall and through the SHED wall. Temperatures 1 feet away from the outer wall surface and at the center of the SHED showed that the temperatures measured 10" from either side of the SHED wall were representative of temperatures several feet away. The air inside the enclosure was being circulated using a small fan to one side of the vehicle. It is not known to what extent the air outside the enclosure was being circulated, but the temperature profile suggests that a similar amount of circulation was present outside the SHED as inside the SHED. As discussed earlier, the amount of circulation will affect the amount of conductive heat transfer across the enclosure walls. The effectiveness of increased circulation drops off as the circulation increases. In other words increasing the air movement from still air to a 10 mph velocity is much more effective than increasing the velocity from 10 mph to 20 mph. Therefore, it is not known how effective an increase in air circulation would be.

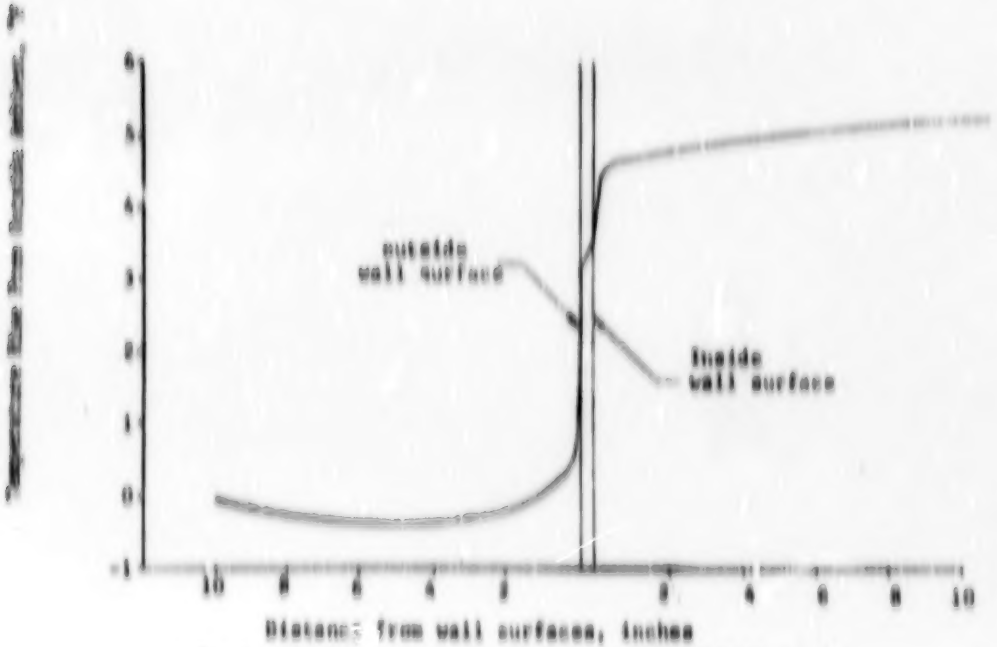


Figure 4-3 Temperature Profile Across SHED Wall at 40 Minutes into Hot Soak Test.

4.3 Tests Conducted with Additional Fans

In order to determine if the use of additional fans to blow air against the enclosure walls can effectively lower the ambient temperature in the enclosure, tests were conducted using additional cooling fans placed as shown in Figure 3-5. Temperature data collected for tests using the New Yorker in the enclosure included the various vehicle temperatures and SHED ambient temperature. These data for individual tests are given in Appendix C along with the hydrocarbon loss during tests with the additional fans and without additional fans.

Data from Appendix C were reduced and plotted in Figures 4-6 through 4-10 along with data presented earlier from the two hour hot soaks conducted in the open and in the shop soak area with the New Yorker. Figure 4-6 shows that the maximum SHED ambient temperatures were reduced by approximately 5°F. The maximum SHED ambient temperature recorded was roughly 91°F. The initial ambient temperatures for tests with and without additional fans appear to have been roughly the same. A statistical T-test applied to the maximum temperature data for tests with and without the additional fans indicates that the difference in maximum temperatures is statistically significant at a 99.9% confidence level. Therefore, it appears that the additional fans do reduce the inner and outer wall surface heat transfer coefficients (f_i and f_o), thereby increasing heat transfer across the enclosure walls. The additional air circulation was not capable of maintaining 86°F or lower maximum temperatures, however.

Although the ambient temperatures were reduced, the carburetor bowl temperatures were not,as seen in Figure 4-7. Figures 4-8 and 4-9 indicate that the change in tank temperatures during the one hour soak was also the same or greater with the additional fans compared to tests without the fans. A statistical T-test applied to the carburetor bowl temperature data indicates that the difference in bowl temperatures was not statistically significant even at a 90% confidence level. Thus, the additional fans did not aid in lowering the vehicle temperatures.

Figure 4-10 shows the hydrocarbon loss during the hour soak for tests with and without the additional fans. The losses were essentially the same. This would be expected due to the fact that the various vehicle temperatures monitored were unchanged due to the additional fans. Whether a change in the vehicle temperatures would have resulted in a difference in the measured emissions would have depended on the condition of the evaporative emission control system, however.

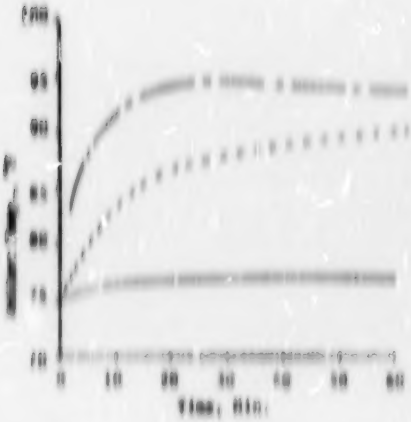


Figure 4-6 Ambient Temp. vs. Time for Hot Soak Tests on New Yorker.

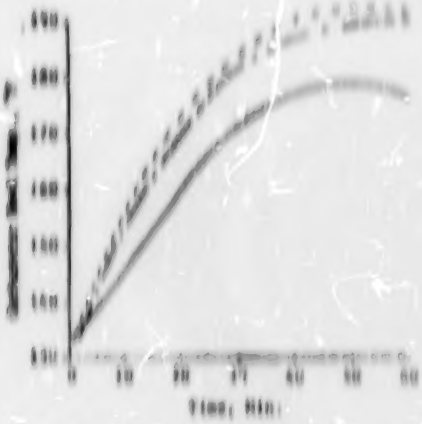


Figure 4-7 Carburetor Bowl Temp. vs. Time for Hot Soak Tests on New Yorker.

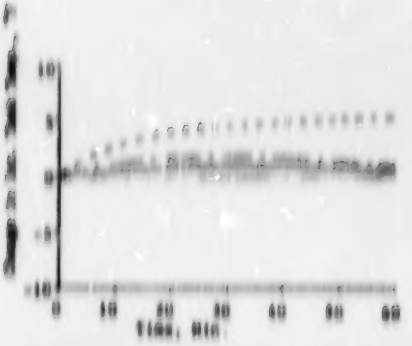


Figure 4-8 Change in Int. Tank Temperatures vs. Time for Hot Soak Tests on New Yorker.

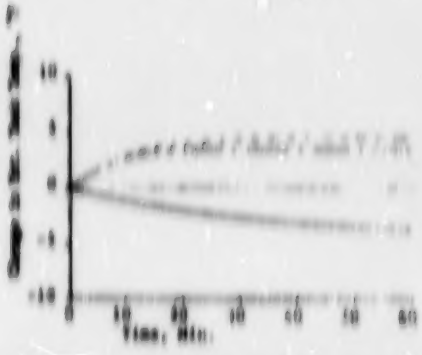


Figure 4-9 Change in Ext. Tank Temperatures vs. Time for Hot Soak Tests on New Yorker.

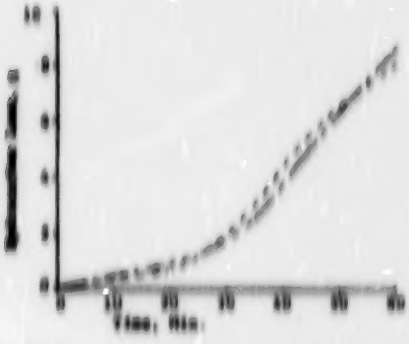


Figure 4-10 Hydrocarbon Loss vs. Time for Hot Soak Tests on New Yorker.

SHED Tests without Additional Vane.

SHED Tests with Additional Vane.

Tests in the Shop Soak Area.

5. Discussion of Results

The most important conclusion to be drawn from the test results is that the enclosure does indeed present a more severe temperature condition than exhibited during a soak in the shop area. It would seem appropriate to keep the ambient temperature in the SHED enclosure between 68 and 86°F as specified for other portions of the test sequence. This would make all test phases consistent. Also, by limiting the temperature to this range instead of a broader range, it would help to reduce test variability.

The important question is whether or not 86°F is a reasonable temperature to maintain. The SAE J171a (1) procedure requires the ambient temperature range be between 76 and 90°F or a 14°F range. If the temperature range were specified to be between 68 and 86°F this would be an 18°F range and thus it would be slightly more liberal but would require a 4°F lower peak ambient temperature.

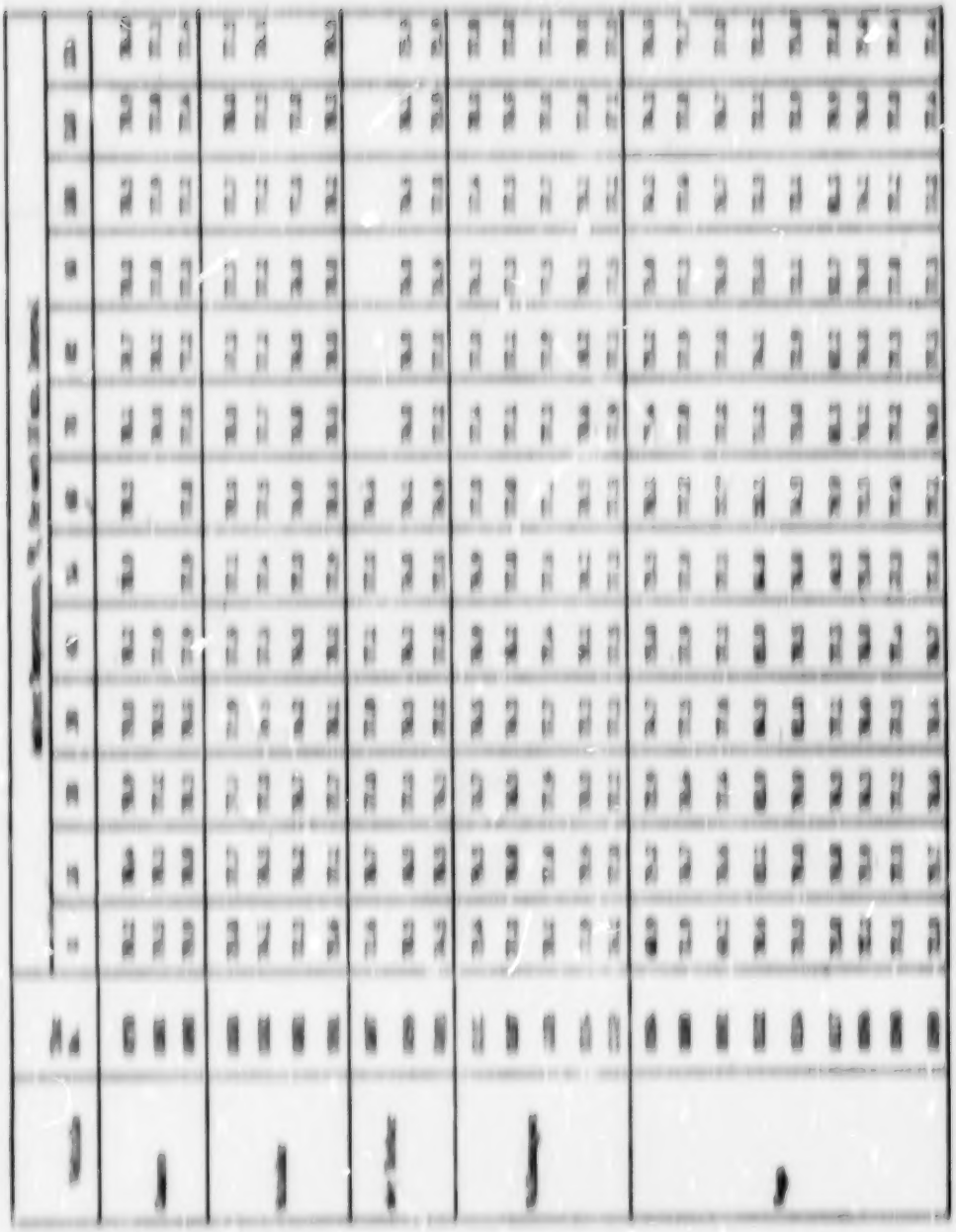
Section 3 of this paper discussed several ways of increasing the heat flow across the enclosure wall. The SAE J171a (1) test procedure suggests that flowing air across the inner and outer wall surfaces can aid in cooling the ambient SHED temperatures. Tests conducted with addition fans inside and outside the SHED did reduce the ambient SHED temperatures by approximately 5°F. Further circulation beyond that employed for those tests would probably not greatly reduce temperatures and therefore other methods of cooling the SHED should be explored.

The maximum temperature recorded for the tests with additional fans was 91°F. This is 5°F above the 86°F maximum which is desirable for testing. Reducing temperatures 5°F could be accomplished in a number of ways including the addition of cooling fins, lowering the ambient temperature several degrees in the soak area, and using more thermally conductive wall materials. These methods are relatively inexpensive and simple compared to a closed loop air conditioning system or a water cooled SHED, but would have to be proven effective experimentally. It is recommended that testing be conducted to show the effectiveness of these methods of cooling. It needs to be shown that temperatures at or below 86°F can be maintained in the enclosure for the hottest vehicle before 86°F is set as a maximum temperature requirement. It is believed at the present time that employing these methods will be able to maintain an 86°F maximum temperature. However, should testing show that these methods cannot meet this maximum temperature level it is recommended that a slightly higher temperature requirement be allowed rather than using an elaborate cooling system. The potential impact of allowing slightly higher ambient temperatures would be that a greater amount of fuel vapors could be generated in the carburetor bowl. The increased amount of vapors generated would be roughly 2 1/2% more vapors generated for every 1°F higher bowl temperatures. The exact % increase would depend on the distillation properties of the fuel and the peak bowl temperatures encountered.

6. References

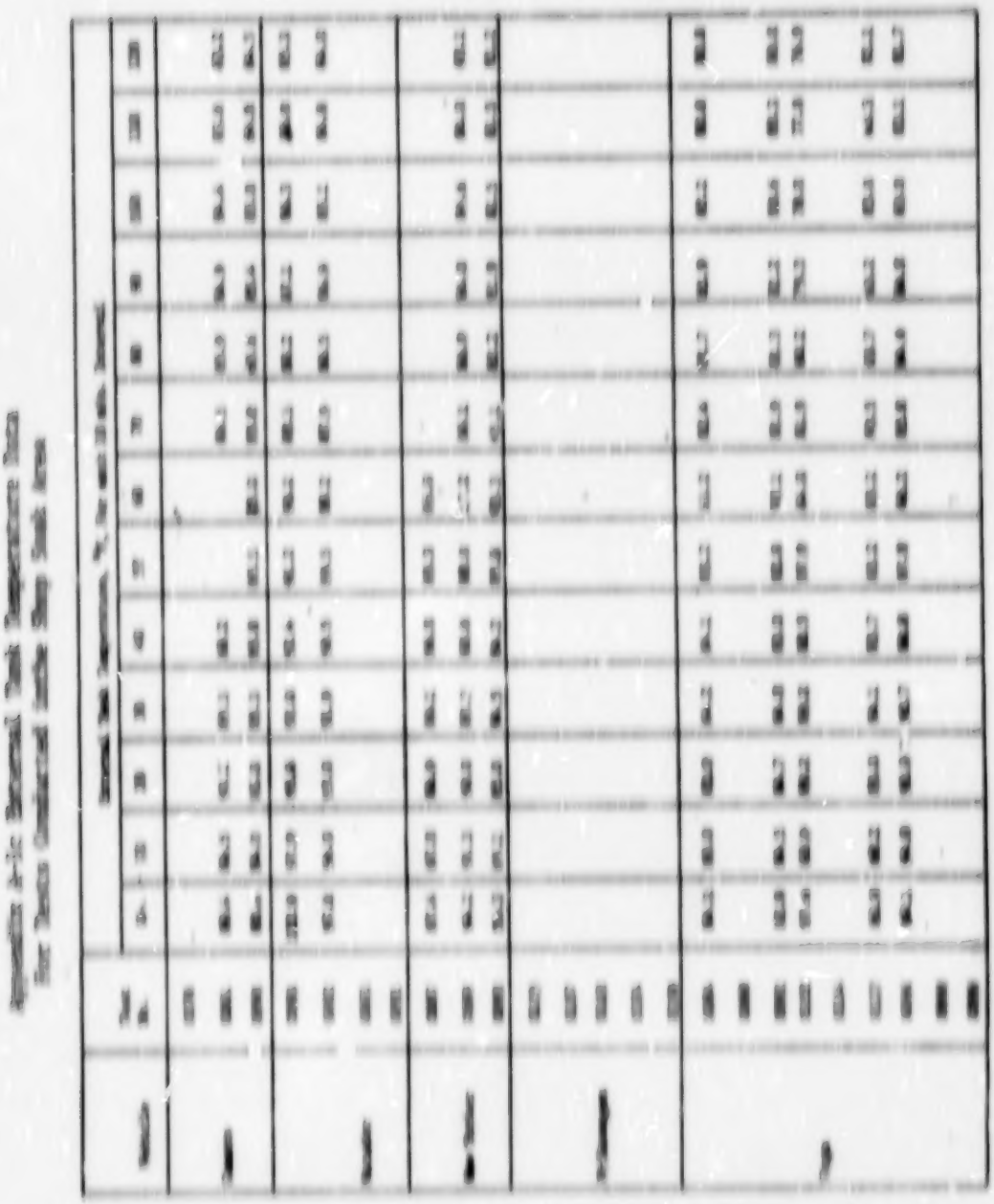
1. "Measurement of Fuel Evaporative Emissions from Gasoline Powered Passenger Cars and Light Trucks using the Enclosure Technique", SAE Recommended Practice, SAE J171a, SAE Handbook.

Appendix A



Appendix A-2b Internal Tank Temperature Data
For Tests Conducted in the Ship Tank Area

Test No.	Internal Tank Temperature, °F, for each Grain Interval												
	0	20	30	35	40	50	60	70	80	90	200	220	240



Appendix A-18 Carburetor Heat Temperature Data
For Tests Conducted in Step Soak Area

Vehicle	Test No.	Carburetor Heat Temperature, °F, for each 2 min. interval												
		0	10	12	14	16	18	20	22	24	26	28	30	32

Appendix A-16. Statistical Temperature Data for Hot Soak Tests Conducted in the Shop Area.

Time, min.	Ambient Temp.			Test Tank Temp.			Test Tank Temp.			Carb. Bowl Temp.		
	N	$\bar{X}$, °F	σ	N	$\bar{X}$, °F	σ	N	$\bar{X}$, °F	σ	N	$\bar{X}$, °F	σ
0	5	75.0	1.1	5	87.5	2.1	4	98.5	6.6	4	135.3	28.7
10	5	77.3	0.7	5	87.6	2.4	4	88.5	5.3	4	138.5	23.5
20	5	77.4	0.5	5	87.3	2.0	4	88.0	3.5	4	142.8	24.3
30	5	77.4	0.5	5	87.3	2.1	4	88.1	2.6	4	150.7	25.3
40	5	77.5	0.5	5	86.9	2.0	4	87.6	2.6	4	134.9	24.6
50	5	77.6	0.6	5	86.3	2.9	4	86.8	2.4	4	136.7	24.5
60	5	77.5	0.4	5	86.1	2.9	4	85.8	2.4	4	136.0	23.4
70	5	77.3	0.6	5	85.6	2.6	4	85.9	2.3	4	135.2	24.7
80	4	77.2	0.6	5	85.5	2.5	4	84.9	2.1	4	131.3	24.2
90	5	77.1	0.5	5	85.0	2.6	4	84.3	2.3	4	130.9	24.6
100	5	77.2	0.7	5	84.7	2.7	4	83.6	2.1	4	148.2	24.6
110	5	77.3	0.9	5	84.2	2.2	4	83.4	2.0	4	145.6	24.5
120	5	76.9	0.8	5	83.8	2.9	4	82.7	2.3	4	142.7	24.2

| | | |

Appendix A-11: Carburetor Heat Temperature Data
Rx. Tests Conducted in the [redacted]

[redacted]	Test #	[redacted]												
		0	10	20	30	40	50	60	70	80	90	100	110	120
[redacted]	[redacted]	139.0	139.3	141.0	141.0	144.0	147.3	144.3	144.0	143.5	141.5	138.5	136.5	133.0
	[redacted]	138.5	139.0	140.0	140.5	140.5	141.0	145.5	146.0	145.5	143.0	140.5	139.0	135.0
	[redacted]	138.0	139.0	140.5	142.0	140.0	144.5	145.5	146.0	145.5	144.0	142.0	139.0	137.0
	[redacted]	137.5	138.5	140.0	142.0	143.0	141.0	144.0	148.5	147.5	145.0	142.0	139.0	137.0
	[redacted]	138.0	139.0	140.0	142.0	140.5	141.0	144.0	147.0	145.5	143.5	141.5	139.5	136.5
	[redacted]	[redacted]	138.5	140.5	144.0	147.0	147.5	148.0	148.5	148.5	146.5	144.0	142.0	139.5
[redacted]	[redacted]	134.5	137.0	141.5	144.5	141.5	144.5			147.0	145.5	143.5	141.5	141.5
	[redacted]	138.5	139.5	140.5	142.0	141.0	143.0	145.5	147.5	144.0	144.5	145.0	143.5	137.0
	[redacted]	138.5	139.0	138.0	140.0	141.5	141.0	141.0	144.5	144.5	144.0	143.0	141.5	140.5
	[redacted]	138.0	139.0	137.5	140.0	140.5	140.5	143.0	144.5	144.5	144.0	143.0	141.5	138.5
	[redacted]	140.0	137.0	137.5	137.5	137.0	140.0	142.0	144.0	144.5	144.0	142.5	141.0	138.5
	[redacted]	[redacted]	140.0	140.0	137.0	138.5	140.5	140.5	142.0	142.5	142.5	140.5	140.5	140.5
[redacted]	[redacted]	138.0	140.0	138.0	136.5	138.0	140.5	141.5	140.5	139.0	137.5	138.5	135.5	133.5
	[redacted]	133.5	134.0	133.0	140.0	136.0	138.5	138.5	138.0	136.0	136.0	134.0	134.5	131.5
	[redacted]	138.5	139.0	137.5	138.0	138.5	138.0	138.5	138.5	138.5	141.0	137.5	136.5	131.0
	[redacted]	136.0	137.0	138.0	137.0	137.5	138.5	138.5	138.5	139.5	139.5	138.0	138.0	136.0
	[redacted]	133.5	138.5	136.0	135.0	135.0	138.0	138.5	140.5	139.5	139.5	138.0	135.0	133.5
	[redacted]	134.5	135.0	136.0	137.0	136.0	137.5	137.5	138.0	138.5	137.5	137.0	133.5	130.0
	[redacted]	138.0	138.5	136.0	136.0	136.5	137.5	138.0	138.5	138.5	136.5	138.5	136.5	133.5
	[redacted]													
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	[redacted]													
	[redacted]													
	[redacted]													
	[redacted]													
[redacted]	[redacted]	134.5	142.5	146.5	145.5	144.5	141.0	141.0	139.0	141.0	140.5	142.0	134.5	136.5
	[redacted]	137.5	141.5	138.0				137.0	136.0	133.5	137.5	143.5	139.5	136.0
	[redacted]	137.0	138.0	137.0	140.0	141.5	151.0	136.0	133.0	148.5	145.0	142.0	137.5	134.5
	[redacted]	133.5	140.5	137.0	142.5	143.5	147.0	138.5	134.5	150.5	145.5	142.5	139.0	136.5
	[redacted]	132.0	140.5	137.0	142.0	144.5	142.0	138.0	135.5	151.0	146.5	143.0	139.0	136.5
	[redacted]	133.5	142.5	137.5	144.0	144.5	140.5	138.0	135.5	151.0	147.0	143.0	140.0	136.5

Appendix A-2e. Statistical Temperature Data for Hot Soak Tests Conducted in the [illegible]

Time, min.	Ambient Temp.			Exh. Valve Temp.			Spr. Valve Temp.			Catch. Bas. Temp.		
	N	$\bar{X}$, °F	σ	N	$\bar{X}$, °F	σ	N	$\bar{X}$, °F	σ	N	$\bar{X}$, °F	σ
0	5	82.6	1.4	5	96.2	2.5	4	92.3	4.3	4	115.8	22.8
10	5	87.8	3.4	5	96.8	3.3	4	94.1	4.3	4	137.4	15.7
20	5	89.0	3.8	5	97.0	3.6	4	94.3	3.8	4	153.0	15.1
30	5	88.6	3.8	5	96.5	3.7	4	94.3	3.8	4	162.3	14.8
40	5	88.7	3.7	5	96.5	3.7	4	94.0	3.6	4	167.4	14.0
50	5	88.3	4.0	5	96.6	3.8	4	93.9	3.8	4	168.3	13.9
60	5	88.4	3.7	5	96.6	4.2	4	93.7	3.7	4	169.0	13.9
70	5	88.3	3.7	5	96.6	4.3	4	93.5	3.6	4	168.8	14.1
80	5	88.0	3.6	5	96.6	4.3	4	93.2	3.6	4	167.2	14.3
90	5	88.0	3.7	5	96.6	4.3	4	93.7	3.3	4	164.5	14.8
100	5	88.2	3.6	5	96.2	4.6	4	93.3	3.3	4	162.7	14.8
110	5	87.8	3.3	5	96.1	4.6	4	92.1	3.0	4	159.8	15.0
120	5	87.5	3.3	5	95.8	4.3	4	91.8	3.1	4	156.1	15.0

Appendix B Temperature Profile Data for Temperatures Across the SHED Wall at 40 Minutes into Hot Soak Test.

	Temperatures (°F) Inside the SHED at a Distance of:							
Test No:	0"	1/2"	1"	2"	4'	6"	8"	10"
1	83.8	85.8	86.0	86.2	87.0	87.0	86.5	87.2
2	85.2	85.5	85.5	85.6	85.8	86.0	85.8	86.0
3	84.6	85.3	85.4	85.2	85.5	85.5	85.5	85.8
Average	84.5	85.3	85.6	85.7	86.1	86.2	85.9	86.3

	Temperatures (°F) Outside the SHED at a Distance of:							
Test No:	0"	1/2"	1"	2"	4"	6"	8"	10"
1	83.5	80.6	80.4	80.4	80.3	80.0	80.1	81.0
2	84.7	81.8	81.5	81.0	80.9	80.7	81.1	81.0
3	84.3	81.3	81.1	81.0	81.1	80.9	80.9	81.0
Average	84.2	81.2	81.0	80.8	80.8	80.5	80.8	81.0

C-1

Appendix C
Vehicle Temperatures for Hot Soak
Tests with Additional Fans

Location	Temperature, °F						
	0 MIN.	10 MIN.	20 MIN.	30 MIN.	40 MIN.	50 MIN.	60 MIN.
	70.1	86.1	89.2	90.0	90.9	91.0	91.1
Ambient	71.1	82.4	84.9	86.0	87.2	88.2	89.6
Temperature	75.1	84.1	86.7	87.8	88.7	89.5	89.5
Mean	74.8	84.2	86.9	87.9	88.8	89.6	90.1
Std. Dev.	3.5	1.7	2.2	2.0	1.9	1.6	1.0
Carburetor	138	160	178	189	195	196	195
Bowl	131	155	172	183	187	189	188
Temperature	133	158	176	186	191	192	192
Mean	135	158	175	186	191	192	192
Std. Dev.	3.8	2.6	4.6	4.6	3.9	3.3	3.5
Internal	88.0	90.0	91.2	92.0	92.2	92.8	93.0
Tank	82.8	86.2	87.2	88.0	88.3	88.9	89.5
Temperature	87.0	89.8	91.1	91.9	92.0	92.0	92.1
Mean	85.9	88.7	89.8	90.3	90.8	91.2	91.5
Std. Dev.	2.8	2.1	2.3	2.1	2.2	2.1	1.8
External	87.9	91.0	92.0	92.3	92.1	92.2	92.2
Tank	82.2	85.8	87.3	87.8	87.6	87.5	88.9
Temperature	85.0	88.2	87.8	88.4	89.0	89.2	89.9
Mean	85.3	87.7	89.0	89.5	89.6	89.6	90.3
Std. Dev.	2.9	2.9	3.6	2.4	2.3	2.4	1.7

Appendix C (continued)
Hydrocarbon Loss for Hot Soak Tests
with Additional Pans

	Hydrocarbon Loss, g						
	0 Min.	10 Min.	20 Min.	30 Min.	40 Min.	50 Min.	60 Min.
	-0-	.38	.89	1.75	4.16	6.33	7.92
	-0-	.42	.73	2.17	5.00	7.21	8.47
	-0-	.29	.71	1.85	4.33	6.19	7.75
Mean	-0-	.36	.78	1.92	4.50	6.58	8.04
Std. Dev.	--	.06	.10	.22	.44	.35	.36

Hydrocarbon Loss for Hot Soak Tests
without Additional Pans

	Hydrocarbon Loss, g						
	0 Min.	10 Min.	20 Min.	30 Min.	40 Min.	50 Min.	60 Min.
	-0-	0.41	0.72	1.23	2.38	4.33	6.23
	-0-	0.42	0.91	1.33	2.81	5.15	7.26
	-0-	0.55	1.09	1.87	4.54	7.53	10.33
	-0-	0.45	1.10	2.26	4.86	7.52	9.09
	-0-	0.50	0.95	1.61	4.32	6.51	8.15
	-0-	0.45	0.94	1.59	4.00	6.80	9.81
	-0-	0.46	0.94	1.77	3.93	6.66	9.20
	-0-	0.49	0.99	1.65	3.97	6.12	8.07
Mean	-0-	0.47	0.96	1.66	3.85	6.35	8.52
Std. Dev.	--	0.05	0.12	0.32	0.85	1.11	1.36